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ABSTRACT

Despite a growing interest in understanding how board diversity shapes firms' innovation, findings about the impact of board diversity have remained mixed. In this paper, we conceptualize board diversity as two forms—deep-level and surface-level—and find that these two forms of board diversity have opposing effects on a firm's innovation. We also theorize how formal and informal social structures can strengthen the positive effect of deep-level diversity yet simultaneously weaken the negative impact of surface-level diversity. We test our hypotheses with a panel of 42,432 firm-year observations from 2000 to 2019. Our paper contributes to the literature on boards and innovation by highlighting and differentiating the mechanisms through which board diversity affects innovation, as well as showing how formal and informal structures can moderate the effects of board diversity.

INTRODUCTION

There is increasing attention in the management and practitioner literature on how board diversity influences firm innovation (Klarner et al., 2020; Useem et al., 2014). Scholars have suggested that board diversity can enhance the monitoring and advising functions of a board, which in turn improves corporate governance and managerial decision making that are beneficial for firm innovation (Tasheva and Hillman, 2019). Indeed, prior research suggests that a diverse board can not only better assess whether certain technology projects or competitive strategies serve a firm well, but can also provide its expertise and relevant resources to help a firm execute a given technology-driven strategy (Klarner et al., 2020; Miller and del Carmen Triana, 2009).

Despite a burgeoning literature stream that examines the influence of board diversity on firm innovation, empirical findings on this relationship have remained mixed. Whereas studies have found that board diversity is positively related to innovation (e.g., Bernile et al., 2018; Miller and del Carmen Triana, 2009), some studies found that such a positive relationship tended to be relevant only for particular forms of diversity (e.g., An et al., 2021; Griffin et al., 2021). On the other hand, such a relationship is absent in other studies (e.g., Hsu et al., 2022); in fact, some studies have even suggested that a diverse board could hurt board functioning (e.g., Adams et al., 2018) and hamper firm innovation (e.g., Genin et al., 2023).

We suggest that these inconsistent findings are due to at least two issues. First, existing studies have under-theorized how board diversity affects a board's monitoring and advising functions, which influence firm innovation. These studies tend to focus on certain diversity categories (e.g., gender, minority status) to explain how these particular diversity measures affect a board's ability to monitor or advise managers during their decision making processes (e.g., Chen et al., 2016; Miller and del Carmen Triana, 2009). However, advances

in diversity research suggest that diversity is inherently multidimensional and has both surface-level and deep-level properties, regardless of the type of diversity itself. “Deep-level” diversity refers to the variety of knowledge and information that arises from less-visible aspects of group members, such as functional experiences and task-relevant knowledge (Harrison et al., 1998; Phillips and Loyd, 2006). By contrast, “surface-level” diversity refers to the salient or visible aspects of board diversity that could trigger social categorization processes and intergroup biases (Phillips and Loyd, 2006; Srikanth et al., 2016). Although these deep- and surface-level aspects could have a differential impact on team- or group-level interactions and performance (Post et al., 2021), scholars have not incorporated these theoretical advances with respect to diversity into board research (Boivie et al., 2016). Second, the effect of board diversity on a board’s monitoring and advising functions are likely dependent on how diverse board members and managers interact, formally or not, with one another (Boyd et al., 2011; Westphal, 1999; Zhu and Chen, 2015). Yet how such board relations affect the relationship between board diversity and a firm’s innovation outcomes remain under-investigated. Only recently have management scholars used multiple case studies, for example, to understand how diverse board members collaborate with managers to shape firm-level innovation decisions (e.g., Klarner et al., 2020). This is an important omission, considering that board social relations could have a moderating influence on the effects of deep- and surface-level aspects of board diversity (Srikanth et al., 2016).

In this paper, we draw on the group diversity literature to develop a theory on how board diversity influences innovation. We begin by separating board diversity conceptually into its deep-level and surface-level aspects, as both deep-level and surface-level board diversity have a differential influence on innovation outcomes (Post et al., 2021; Srikanth et al., 2016). Specifically, we argue that because deep-level board diversity increases informational or cognitive diversity among board members, deep-level board diversity

facilitates a board's ability to advise and engage with managers in order to solve innovation-related problems (Bantel and Jackson, 1989; Harrison et al., 1998). By contrast, surface-level diversity can exacerbate social categorization processes (Phillips and Loyd, 2006; Tajfel et al., 1971) and thereby undermine coordination between boards and management, which negatively impacts innovation. Next, we also suggest how formal and informal social structures (i.e., board-CEO committee overlap and board-CEO outside social ties, respectively) (Gulati and Puranam, 2009; He and Huang, 2011) can moderate the effects of deep-level and surface-level diversity on firm innovation. We theorize how these social structures not only can strengthen the positive effect of deep-level board diversity but also can weaken the negative effect of surface-level board diversity. We test our hypotheses with a panel of 42,432 firm-year observations from 2000 to 2019, and find support for most of our hypotheses.

This study makes three major contributions. First, it contributes to the literature on innovation and board research (Boivie et al., 2016; Hsu et al., 2022; Miller and del Carmen Triana, 2009). Although the topic of board diversity has been garnering attention and a growing number of studies are examining how diversity affects innovation (e.g., Bernile et al., 2018; Griffin et al., 2021), there is still scarce systematic research that builds on advances in the diversity literature to understand the influence of board diversity on firm-level outcomes. Whereas prior research supports that different diversity dimensions of board members can influence firm innovation to varying degrees (e.g., An et al., 2021; Griffin et al., 2021), studying board diversity with respect to its deep- and surface-level aspects can further explain how board diversity positively or negatively affects firms' innovation outcomes (Post et al., 2021). Our study complements this limited research stream on board diversity and introduces insights into the mechanisms through which board diversity affects board decision-making processes that shape firm innovation (Boivie et al., 2016; Miller and del

Carmen Triana, 2009; Tasheva and Hillman, 2019). These mechanisms provide a more nuanced view of the conditions when board diversity is likely to exert a positive or negative impact on innovation.

Second, understanding how formal and informal structures can moderate the influence of board diversity on innovation has important implications for the organizational design of boards to ensure effective board decision-making (Boivie et al., 2016; Harrison, 1987). The literature on boards suggests that the social structure of board members is an important form of social capital or resource for firms (Hillman and Dalziel, 2003). A key argument in this stream of research is that more socially connected directors enhance resource provision to a firm that, in turn, enhances firm performance, as evidenced by better strategy making and implementation (Tasheva and Hillman, 2019). In contrast, our study and findings suggest that these social connections are not only inherently valuable on their own but also play an important role in strengthening the positive effects of board diversity on firm innovation, thus suggesting how social relations among board members and management could either enhance or constrain a diverse board's ability to create value for a firm. More generally, our study contributes to the call for more research on strategies that organizations may use to manage the visible and less visible forms of diversity within their respective organizations (Post et al., 2021); specifically, we show how social structures (or the lack of) can enhance or attenuate the effects of surface-level and deep-level board diversity on firm innovation outcomes.

Finally, we contribute to the corporate governance literature on board-CEO relations. Scholars have recognized that the social interactions between boards and their respective CEOs have crucial implications with respect to firm governance (Boyd et al., 2011). Most prior studies have largely focused on the instrumental aspect of these board-CEO relations (i.e., whether board-CEO ties can be leveraged to enhance firm value for managers). However, our findings suggest that a non-instrumental (and less examined) psychological

aspect of board-CEO relations also benefits firms by moderating the negative impact of social categorization processes, especially for diverse boards. Thus, our study complements existing research by articulating how board-CEO relations influence the effect of boards as evidenced by a firm's innovation-related outcomes (e.g., Boyd, 1995; Boyd et al., 2011; Westphal, 1999).

THEORY AND HYPOTHESES

Board diversity and firm innovation

The corporate governance literature highlights two major functions of boards. First, according to the agency perspective, boards are entrusted to monitor management in accordance with shareholders' interests. Given the separation of ownership from control, CEOs and other top managers may act in self-interest and make decisions that are not aligned with shareholders' best interests (Jensen and Meckling, 1976); in turn, boards must scrutinize managers to reduce such agency costs and ensure that managers' actions maximize shareholder value (Sapra et al., 2014). Second, the resource dependency perspective suggests that boards provide resources and counsel that are critical to a firm's success (Hillman and Dalziel, 2003; Pfeffer and Salancik, 1978). Boards are typically made up of experts with financial and legal expertise, and some board members may even include top managers from other firms, all of whom bring skills, experience, and access to information that they use to advise their respective firms on administrative and strategic issues (Balsmeier et al., 2014; Hsu et al., 2022). Hence, through monitoring and resource provision, boards ensure that management takes strategic action and engages in issues that are in a firm's best long-term interests.

To the extent that the provision of monitoring and advice by a board helps steer a firm's innovation activities (Adams and Ferreira, 2007), board diversity warrants strong attention. From the monitoring perspective, diversity among directors ensures diverse

expertise, experience, and perspectives, all useful for evaluating the quality and potential of innovation proposals (Balsmeier et al., 2014; Klarner et al., 2020). Innovation-related projects can be complex, and the related costs and benefits can be difficult to evaluate ex-ante (Harris and Raviv, 1991; Hirshleifer et al., 2018). A board with a more diverse set of skills and experience is better positioned to evaluate proposals and more likely to identify and filter those proposals that add little value to a firm. From the resource provisioning perspective, a diverse board is also better positioned to engage with CEOs by discussing and choosing innovation strategies (Westphal, 1999). Given board members' access to information from different domains, their joint efforts to set an innovation agenda are likely to be more creative than those of a board made up of directors with homogeneous demographics. Diverse boards tend to provide better advice, to possess a wider variety of skills among their members, and to offer more creative input for their respective CEOs, especially when there are issues or concerns with respect to innovation projects (Klarner et al., 2020; Useem, 2006).

Indeed, anecdotal evidence suggests that board diversity does matter, as boards increasingly innovate alongside management (Balsmeier et al., 2017; Kor, 2006). Some board directors strengthen their involvement by forming committees to work with CEOs on technology and innovation (Useem et al., 2014). For instance, the board of Diebold, a U.S. manufacturer of ATMs, created a Technology Strategy and Innovation Committee whose responsibilities included providing management with a "sounding-board" during technology direction-setting as well as enhancing "management's network of contacts and connections with relevant technology industry experts and companies" (Diebold, 2014).

However, findings from recent empirical studies that examine the relationship between board diversity and firm innovation have remained inconsistent.[1] On the one hand,

[1] We conducted a literature review on 53 empirical studies focusing on board diversity (as the independent variable) published in leading management, finance and accounting journals in the past 20 years from 1994-

some studies have reported a positive effect of board diversity on firm innovation. For example, Bernile et al. (2018) found that board diversity (as measured across gender, age, ethnicity, educational background, and board and financial experience) among U.S. firms is not only positively associated with firms' patenting output, but that such firms' patents are also likely to receive a higher number of citations. An et al. (2021) found that more diverse boards are also more likely to engage in more exploratory innovation. In studies focusing on particular diversity dimensions, Chen et al. (2018) and Griffin et al. (2021) found that gender diverse boards are more likely to have more patents, novel patents, and greater innovation efficiency. On the other hand, other studies highlight that the effect of board diversity on firm-level innovation is not necessarily positive. For instance, Hsu et al. (2022) did not find any significant relationship between board diversity and innovation outcomes. An et al. (2021) meanwhile reported that among different diversity dimensions, professional and educational background diversity tends to be positively related to patenting activity, whereas other dimensions such as demography or cultural diversity were not significant predictors of firm innovation. Similarly, Genin et al. (2023) found that a board's demographic diversity has a negative impact on a firm's ability to produce path-breaking innovations.

These inconsistent findings have perhaps led some scholars to suggest that the effect of board diversity on innovation is contingent on contextual factors pertaining to the firms themselves (Zona et al., 2013), as well as the competitive (An et al., 2021) and institutional environments (e.g., Cumming and Leung, 2021; Zhang, 2020) in which they operate. While a

2023 (please refer to "Online Appendix: Literature Review on Board Diversity, 1994-2023" for more details on our methodology and details). From the literature review, we offer four observations: (1) empirical articles that examine the effect of board diversity on innovation (9% of studies) comprise the most recent theme, which has only emerged in the past five years; (2) most studies (70%) examine board diversity using demographic-based measures (e.g., gender, ethnicity, age); (3) in explaining how board diversity affects various outcomes, the mechanisms suggested in most studies fall into two broad categories: (a) information and (b) cognitive biases; (4) it is not clear from the literature review whether certain diversity types are associated with particular mechanisms; studies have argued how demographic (e.g., gender) and non-demographic (e.g., experience) forms of board diversity can either benefit/hinder board functioning because of diverse information or facilitate social biases or categorization.

contingency perspective of board diversity may help explicate the conditions in which diversity matters, this perspective does not directly address why some forms of diversity have shown ambiguous outcomes. Indeed, most studies tend to examine whether board diversity types (e.g., demographic, vs. non-demographic diversity) affect board function. Moreover, few studies theorize about the nature of diversity beyond their descriptive labels relating to certain measures (e.g., gender, experience). This is an important shortcoming since diversity research have suggested that diversity could be better conceptualized into its deep- and surface-level properties (Post et al., 2021; Srikanth et al., 2016), which can better explain why a particular type of diversity (e.g., gender) may have positively and negatively influence board functioning and, hence, innovation outcomes.

In the next section, we draw upon research on deep-level and surface-level diversity to explain how deep- and surface-level board diversity affect a firm's innovation outcomes.

Deep- vs. surface-level board diversity and firm innovation

Recent advances in diversity research have recognized that diversity is a "double-edged" sword because of the opposing effects that diversity may have on group performance outcomes (Srikanth et al., 2016). In other words, diversity may have countervailing influences that build upon information processing and social categorization theories.

The information processing perspective suggests that group diversity arising from a variation of team composition increases opinions, knowledge, and multiple perspectives (Bantel and Jackson, 1989; Gao et al., 2021; Singh and Fleming, 2010), all of which help to improve information processing, creativity, and decision-making within groups. This form of diversity is often referred to as "deep-level" diversity because such a variety of knowledge and information arises from less-visible aspects of group members; these aspects include functional experiences, task-relevant knowledge, values, or even personalities (Harrison et al., 1998; Phillips and Loyd, 2006). Prior studies have shown that team members with deep-

level diversity often make better decisions or demonstrate more creativity because of their increased variety of information and skills (Harrison et al., 2002).

In the context of boards, we expect that boards with deep-level board diversity are likely to enhance innovation for their respective firms. First, from an advising perspective, deep-level board diversity implies that board members possess a diverse set of knowledge, expertise, and experiences (Tasheva and Hillman, 2019), all of which position them well to mentor CEOs on company innovation-related issues or matters (Shen, 2003). The availability of directors with such diverse expertise suggests that CEOs are also more likely to seek the advice from well-informed board members as they formulate and refine company strategies (e.g., technological projects and investments to pursue).

From the monitoring perspective, a board with deep-level diversity is also more capable of overseeing and scrutinizing a CEO's decisions with respect to innovation-related matters. Because CEOs are insiders and thus better informed than board members about their respective firms' technological projects, an information asymmetry exists between a board and its CEO (Bergh et al., 2019; Zhang, 2008). A CEO could exploit such information asymmetry to push for decisions that favor the CEO's interests rather than that of shareholders. However, this information asymmetry and its associated agency issues will be mitigated if a board is more well-informed. Specifically, a board with deep-level diversity is better equipped to engage in deeper and meaningful discussions with its CEO in order to dismiss either poorly conceptualized projects with high opportunity costs, or dismiss those projects that do not maximize value for shareholders (Klarner et al., 2020).

Collectively, our arguments suggest that deep-level board diversity is positively associated with a board's advising and monitoring functions, which are crucial for facilitating innovation decisions and investments. Thus, we posit the following hypothesis:

Hypothesis 1a: Deep-level board diversity is positively associated with innovation.

In contrast, social categorization theories suggest that group diversity may also lead to negative consequences with respect to group performance (Tajfel et al., 1971). This perspective highlights how group diversity, especially that related to demographics, may trigger social categorization processes through which members may strongly identify with others whom they perceive to be in the same social category while differentiating themselves from others who are outside that category (Rhodes and Baron, 2019). Consequently, group diversity may lead to weaker communication and group cohesion, while exacerbating conflicts and fault lines among group members. In particular, consensus-building efforts may be weaker when race and ethnic diversity among group members are higher (McPherson et al., 2001). Scholars have contended that such negative consequences may arise due to more visible aspects of diversity, such as race, gender, or ethnicity. Because these salient diversity characteristics are also often associated with a group member's relative status within a social hierarchy (e.g., men perceived as higher in status than women), they can trigger in-group or out-group biases that weaken group performance (Phillips and Loyd, 2006). Because such diversity characteristics are often visible, diversity researchers have typically referred to these forms of diversity as "surface-level" diversity, which contrasts with the "deep-level" forms of diversity that are less salient and less observable (Harrison et al., 1998).

We posit that surface-level board diversity may undermine how effectively board members collaborate with CEOs. From the board advising perspective, surface-level board diversity can create barriers and challenges that prevent board members from sharing advice that could improve innovation outcomes. Specifically, demographic differences may impact how CEOs and board members cognitively categorize each other: either as part of an in-group or out-group; this in turn could lead to faction formation or subgroups within a given board, thereby making the integration of different perspectives more challenging (Lau and Murnighan, 1998). CEOs and board members with different perspectives and backgrounds

may have difficulty reaching consensus on certain issues, and potentially experience conflicts and slower decision-making (Davis and Eisenhardt, 2011).

From the board monitoring perspective, surface-level diversity is also likely to inhibit a board's ability to oversee its respective CEO effectively when there is information asymmetry between board members and the CEO. As previously mentioned, the information asymmetry between boards and CEOs is likely to be mitigated when board members have diverse information and knowledge. However, when surface-level board diversity is high, board members are more likely to face sub-group conflicts (Lau and Murnighan, 1998). With weaker board member cohesion, a board is less able to draw on its diverse expertise and knowledge domains, which are both crucial for managing information asymmetry between a board and its CEO. Rather than working together, a board and its CEO then are less likely to reach consensus on issues regarding innovation-related choices, especially proposals with high-impact outcomes that are often complex and uncertain (Harris and Raviv, 1991; Hirshleifer et al., 2018). The subjectivity resulting from complex innovation project proposals may leave more room for debate for a board whose directors hold different beliefs from those of its CEO. Instead, a CEO could also seek to promote his or her own interests over those of the firm, increasing agency issues for the board to handle. Thus, surface-level differences may distract board members from focusing on important issues (Paruchuri et al., 2006).

Because surface-level board diversity undermines a board's advising and monitoring functions, we contend that surface-level board diversity is likely to undermine collaborative and innovation efforts:

Hypothesis 1b: Surface-level board diversity is negatively associated with innovation.

Overall, we contend that deep-level board diversity increases a CEO's access to a more informed board that facilitates innovation; however, surface-level board diversity may

undermine informational benefits because of social categorization processes. Importantly, we note that deep-level diversity and surface-level diversity are two different aspects of diversity that are not measure-specific; put differently, any diversity measure can have both deep- and surface-level properties but to different extents. For instance, in the context of boards, experience diversity is inherently cognitive and exists in the minds of directors, and thus is not visible and more closely associated with deep-level forms of diversity than with surface-level forms of diversity (Jackson et al., 1995; Srikanth et al., 2016). On the other hand, while nationality or gender diversity may also be 'information-rich' (i.e., individuals from different countries or gender may have various perspectives, values, and personalities), they comprise outwardly visible characteristics that tend to trigger social categorization and induce biases (Harrison et al., 1998; Jackson et al., 1995). We contend that such social categorization processes are especially likely among group members who are unfamiliar with one another and may rely on heuristics to guide social interactions. This is not to imply that nationality or gender diversity do not have deep-level characteristics, but rather that the informational benefits associated with their deep-level properties can be diminished in the presence of such social categorization biases. Thus, 'visible' diversity measures such as nationality or gender tend to be associated with 'surface-level' forms of diversity rather than 'deep-level' forms of diversity (Jackson et al., 1995).

In the next section, we discuss how the benefits of deep-level board diversity may be strengthened or how the costs of surface-level board diversity may be weakened by social structures between boards and their respective CEOs.

Social structures and board diversity

Although a diversity of backgrounds may drive directors' interactions, their behaviors are likely to be moderated by the social structures in which they are embedded (Boyd et al., 2011; Gulati and Westphal, 1999). Prior studies have suggested that social structures among

actors can be broadly classified into two types: formal and informal social structures (e.g., Clement and Puranam, 2017). Formal social structures are those in which social relationships among actors are explicitly specified to achieve organizational tasks or goals and are defined independently of the personal characteristics and relations of actors occupying these positions (Scott, 1992). In contrast, informal social structures refer to the interpersonal relations that emerge as actors pursue their own instrumental and socio-emotional needs (He and Huang, 2011; Krackhardt, 1994). Thus, formal social structures are likely to guide and structure communication between actors, whereas informal social structures are likely to be unstructured and shared among actors engaging with one another.

We contend that organizational structures, both formal and informal, guide social behaviors and interactions between boards and CEOs (Boyd et al., 2011; He and Huang, 2011; Shen, 2003). In what follows, we examine how formal structural arrangements (i.e., board-CEO committee involvement) as well as informal relationships (i.e., external ties between board members and CEOs) moderate the influence of board diversity on firm innovation.

The moderating role of formal board structures: Board-CEO committee co-involvement

Unlike board meetings convened to discuss or address strategic issues, board committees are created for a specific task (e.g., search for leadership) delegated to a smaller group of directors (Boivie et al., 2012; Field et al., 2013). Beyond executive, compensation, and audit committees, boards also appoint committees for a variety of other issues pertaining to innovation, strategic planning, marketing, or risk management (Harrison, 1987; Kesner, 1988).

While all board members (including the CEO) may be formally appointed to a board, they vary in their degrees of participation on committees for various reasons. Busy directors for example may have other appointments that limit their involvement to core decision-

making; others may avoid committee involvement because of role conflicts (e.g., compensation committees) or because they lack the expertise required (e.g., audit committees). Nevertheless, board committee membership formalizes directors' and CEOs' involvement in the decision-making process. Barring regulatory stipulation or conflict of interests, CEOs and directors can serve on multiple committees of a single board (Ferris et al., 2003). A direct consequence of board committees is that such formal structures create a formal organizational arrangement that enables a CEO and board members to work together (Clement and Puranam, 2017).

We contend that this arrangement is likely to amplify the positive effect of a board's deep-level diversity on its firm's innovation outcomes. From the board monitoring perspective, formal board committee arrangements can help reduce information asymmetry between board members and CEOs. Because directors involved in board committees often schedule meetings (beyond full board meetings) to discuss committee-specific matters (Harrison, 1987), a CEO who is involved in various committees with select board members will be more socialized with certain members of the board. In turn, board members are also likely to gain insights into firm-specific or CEO-specific information gleaned through their formal interactions. From the board advising perspective, we also expect that the presence of board members and CEOs in board committees will also further amplify the ability of a board with deep-level diversity to provide advice and counsel to its CEO. Such formal arrangements will not only boost familiarity among board members, but CEOs are also then more likely to have more opportunities to tap into different perspectives on a board with deep-level diversity in order to improve innovation-related outcomes (Ter Wal et al., 2020).

In contrast, when there are fewer such formal committee structures, we contend that CEOs will have less frequent involvement with board members, thus weakening a board's monitoring and advising roles that necessarily inform a firm's innovation-related decisions.

Even if a board has deep-level diversity, the benefits of deep-level diversity for innovation outcomes will be limited by a lack of such formal social structures. Thus, we posit the following moderation hypothesis:

Hypothesis 2a: Formal structures (i.e., board-CEO committee co-involvement) strengthen the positive effect of deep-level board diversity on innovation.

We also maintain that these formal structures are likely to attenuate the negative impact of surface-level board diversity on innovation outcomes. First, from the board monitoring perspective, formal structures can help bridge information asymmetry between board members and CEOs. Because board members involved in committees with CEOs are more likely to interact with CEOs whom they otherwise would not (Clement and Puranam, 2017), formal structures can help diminish the negative impact of social categorization processes. While demographic differences may foster the formation of subgroups or factions within a board with high surface-level diversity (Lau and Murnighan, 1998; McPherson et al., 2001), formal structures like board committees would force board members to look beyond their in-group or out-group biases to collaborate on an issue at hand. Second, from an advising perspective, formal structures could also reduce the negative impact of surface-level diversity on a board's willingness to offer advice. Instead, board members who must work with CEOs on the same committee are more likely to shift their attention away from their salient differences in diversity characteristics to focus instead on the committee's objective task (Harrison et al., 1998).

By contrast, for a board in which the average director's involvement in board committees with a CEO is low, the work of board members amounts to a division of labor guided by social categorization processes introduced by surface-level diversity (Phillips and Loyd, 2006); in other words, board members may follow their in-group or out-group biases and choose to work with specific individuals whom they perceive to be like themselves

(McPherson et al., 2001; Rhodes and Baron, 2019). In extreme cases in which neither directors nor CEOs are members of any committee, they have even fewer opportunities to interact with other members beyond their board-wide meetings. Thus, without the common involvement of board members and CEOs on committees, social categorization processes are more likely to dominate board and CEO interactions. Consequently, board members are less likely to collaborate and engage with CEOs in innovation-related discussions (Harrison et al., 1998), impairing both the board's monitoring and advisory functions. In such situations, the cost of surface-level diversity is high, as reaching consensus on strategic innovation decisions becomes more challenging. Hence, we posit that:

Hypothesis 2b: Formal structures (i.e., board-CEO committee co-involvement) weaken the negative effect of surface-level board diversity on innovation.

The moderating role of informal social structures: Board-CEO external ties

Beyond board-CEO interactions facilitated by formal committee arrangements, board members and CEOs may also interact outside of the focal firm. Directors and CEOs often serve on boards of different firms, or they may have common affiliations in various external organizations and thus engage in different activities and in various capacities in such organizations. Board members and a CEO of a focal firm could share one or more external social ties with one another (Westphal, 1999). Unlike the case in formal board committee arrangements, these external social ties between a board and its CEO are unstructured (Krackhardt, 1994) and are not formally arranged to address a particular organizational task that the focal board faces. However, the presence of such external social ties may shape how board members and a CEO interact among themselves within the focal board, and in turn affect how board diversity influences innovation.

We suggest that the external social ties between board members and CEOs are likely to strengthen the positive effect of deep-level board diversity on innovation outcomes. From a

board monitoring perspective, these external social ties can bridge information asymmetry between board members and CEOs. A conventional view of these external social ties is that these ties serve as conduits to enhance information access and flow among themselves (Westphal, 1999). When board members and CEOs have social interactions beyond the focal board setting, board members can develop a more comprehensive understanding about their CEO's background, knowledge, and preferences, all of which may be difficult for board members to learn solely with their limited interactions within the focal firm. If board members are more informed about their CEO, then they are more likely able to assess their CEO's intentions and assess whether these intentions are aligned with those of shareholders.

From a board advising perspective, external social ties would also enable board members to share better advice. With a stronger sense of familiarity and trust developed from their external social interactions, board members are more likely to be open and share their knowledge and perspectives with a CEO (Tasheva and Hillman, 2019). This is crucial if board members hold critical knowledge needed to enable path-breaking innovations (Genin et al., 2023), as they become more willing to share their expertise if they sufficiently trust their respective CEO (Srikanth et al., 2016). Moreover, outside interactions with board members may allow CEOs to be acutely informed about board members' functional backgrounds and experiences, as well as their idiosyncratic knowledge or expertise from which managers can potentially draw upon to make better innovation-related decisions (c.f., Zhu and Chen, 2015).

On the contrary, the fewer the outside interactions between board members and CEOs, the less likely they are informed about one another; in turn, this could limit the ability of a board with deep-level diversity to effectively monitor or provide informational resources to its CEO. Hence, we posit the following hypothesis:

Hypothesis 3a: Informal structures (i.e., board-CEO external social ties) strengthen the positive effect of deep-level board diversity on innovation.

We also contend that board-CEO external ties are also likely to weaken the negative impact of surface-level board diversity. Research in social psychology suggests that social categorization processes are less likely to be triggered between two actors if they share multiple group memberships for at least two reasons. First, social categorization heuristics become less salient when individuals are represented in different contexts (Wenzel et al., 2007). Because of their multiple associations with various social groups, these individuals are less likely to become saliently classified into a certain social category. Rather, individuals in multiple categories are more likely to be decategorized and become less associated with any category (Brewer and Miller, 1984). Second, individuals in multiple social categories are likely to be perceived by others as complex, making it cognitively challenging to classify them into distinct categories (Hewstone et al., 2002). This may naturally weaken any in-group or out-group perceived associations because such categorization biases become challenging to apply.

In the case in which board members have external ties with CEOs, we suggest that these ties can attenuate the social categorization tendencies associated with surface-level board diversity, and consequently improve a firm's innovation outcomes. The external ties capture the multiplex relationships that board members and CEOs have with one another in different social contexts (Burt, 1980). With more common external ties, diverse board members and CEOs are less likely to perceive that demographically different others belong to out-groups (Belliveau et al., 1996). From a monitoring perspective, the reduction in social categorization tendencies is also likely to reduce information barriers between board members and CEOs, allowing board members to oversee a CEO's activities and decisions more effectively and ensure that the firm engage in value-creating innovations. From an advising perspective, the reduction in social categorization tendencies will enable board members to perceive a CEO as an in-group member rather than as an out-group member, and

thus be more willing to share information and provide counsel that could be crucial for making innovation-related investments. Thus, these external social ties can help to weaken the negative impact of surface-level board diversity on innovation outcomes.

On the other hand, when board members and CEOs lack such common external social ties, their social categorization biases may become salient as there are fewer opportunities to perceive how demographically different members could be cognitively similar with respect to other dimensions (Hewstone et al., 2002). These biases could undermine a board's monitoring and advisory roles that are important for promoting a firm's innovation outcomes. These arguments suggest that board-CEO external social ties may be especially helpful in attenuating the social categorization processes associated with surface-level diversity:

Hypothesis 3b: Informal structures (i.e., board-CEO external social ties) weaken the negative effect of surface-level board diversity on innovation.

Figure 1 presents a summary of our key mechanisms underlying our theory of how board diversity shapes firm innovation. In the next section, we present an empirical analysis of archival data to test our hypotheses.

——INSERT FIGURE 1 ABOUT HERE——

METHOD

Data and sample

We construct our data from several sources. Our primary data source of biographical information of directors and CEOs is the BoardEx database from Management Diagnostics Limited. The BoardEx database contains information on personal profiles, education histories, employment histories (including beginning and ending date/year for various roles), and social activities (e.g., club memberships). We draw the main information for our paper from the data on personal profiles and employment histories. Our sample begins in 2000 and

ends in 2019.[2] We collect firm-year patent and citation information from the patent database made available by Kogan, Papanikolaou, Seru, and Stoffman (2017) (henceforth KPSS).[3] To construct our control variables, we collect personal profiles and board information from the BoardEx database, financial statement information from the CRSP/Compustat merged database, and institutional shareholding information from the Thomson-Reuters Institutional Holdings (13F) database. Finally, we restrict our sample to publicly listed firms in the U.S.[4]

We merge the BoardEx database with the CRSP/Compustat Merged database in the following way. The BoardEx database provides four company identifiers: International Security Identification Number (ISIN), CIK, the company name, and "Company ID." We merge "Company ID," which is unique to the BoardEx database, with PERMNO in the CRSP/Compustat merged database by using CIK or CUSIP (derived from ISIN). We then verify the accuracy of this matching procedure by comparing the company names in both databases. The KPSS database contains all patent data granted by the United States Patent and Trademark Office (USPTO) from 1926 to 2020. Also, the KPSS database provides PERMNO for a patent assignee. Our final sample consists of a panel of 42,432 firm-years.

Dependent variable

Innovation. Following the extant literature (Ahuja, 2000; Cockburn et al., 2000), we use patent-based metrics to capture firms' innovation. We focus on two measures for a firm's forward-looking innovation outcomes: *patents* and *citations*.[5] First, the *patents* variable captures the number of patent applications that are eventually granted by the USPTO office to the focal firm in the period t+3. Following the literature, we use a lag structure of three years

[2] Following Engelberg et al. (2012) and Fracassi and Tate (2012), we choose the sample from 2000 onwards, as the coverage before 2000 is limited.
[3] Data are available from https://github.com/KPSS2017/Technological-Innovation-Resource-Allocation-and-Growth-Extended-Data
[4] NYSE/AMEX/NASDAQ-listed firms.
[5] Our results are qualitatively similar when we use other measures of innovation output, including truncation-bias-corrected forward citations (Hall et al., 2001) and average citations, measured as citations over patent counts.

because of the long-term nature of innovation, as it takes time for patents to be filed (An et al., 2021). When constructing our patent count measure, we use patent application year instead of grant year, as the former better represents the timing of innovation activity (Griliches et al., 1987; Hall et al., 2001).

Second, to measure patent influence, we construct the *citations* variable by using the number of forward citations received by a firm's patent applications that are eventually granted by the USPTO office filed by the focal firm at t+3. Because patents in certain technology classes may receive disproportionately more citations than those in other classes (e.g., due to external industry trends in technology development), we follow the approach taken in prior studies to adjust the citation count for its technology class (e.g., Gao et al., 2020; Seru, 2014). We do this in several steps. In the first step, we calculate the average number of forward citations of all patents in the same technology class and filed in the same year (i.e., the 'class-year average'). In the second step, we scale each patent's forward citation count by the class-year average. In the last step, we sum up the adjusted citation counts of all patents filed by a firm for each year in our dataset.

These two measures thus capture two important aspects of firm innovation. To reduce skewness in our dependent variables, we use the natural logarithm transformation of both *patents* and *citations*, plus unity.

Independent variables

Deep-level board diversity and surface-level board diversity. To construct our deep-level and surface-level board diversity measures, we collect data for several board diversity dimensions. To operationalize deep-level and surface-level board diversity, we follow the literature on teams by selecting diversity measures that are closest in terms of representing deep-level and surface-level aspects of diversity (Jackson et al., 1995). *Deep-level board diversity* pertains to differences in the knowledge and expertise of board members; Jackson,

May, and Whitney (1995) suggests that diversity measures such as organizational tenure and task experience are closely related to a diversity of information and skills. Thus, we collect data on board members' industry experience and board tenure. These two measures capture two different aspects of deep-level board knowledge: whereas industry experience captures the knowledge and expertise of board members from outside the firm, board tenure captures the extent to which board members have firm-specific knowledge (Jackson et al., 1995). To compute board members' industry experience, we use the classification system based on Fama-French five industry codes and code for industries in which a director has had prior working experience. We compute board tenure by using the numbers of years a board member has been appointed to a board. For each board every year and for each of the two dimensions, we calculate Blau's (1977) index as $(1 - \sum {p_i}^2)$, in which p_i is either the fraction of board members that are from the same industry or have similar board tenure. To derive the *deep-level board diversity measure*, we compute the equally-weighted average of the two Blau's indices for industry experience and board tenure.

In contrast, s*urface-level board diversity* is associated more with salient diversity differences among board members. For instance, Jackson, May, and Whitney (1995) suggest that diversity types relating to gender, race, ethnicity, or nationality are 'physical features' and thus more related to surface-level forms of diversity. To construct our surface-level board diversity measure, we collect data on board members' gender, ethnicity, and nationality, and then code these characteristics at the board member level. Next, for each of these three dimensions, we calculate Blau's (1977) index as $(1 - \sum {p_i}^2)$, in which p_i is either the fraction of board members that are of a specific gender, ethnic group, or nationality.[6] To

[6] There are 68 nationality groups in our sample. For cases in which a director's nationality is missing (39% of our director-firm-year sample), we exclude the director from both the nominator and denominator when we calculate the Blau's index.

derive the s*urface-level board diversity measure*, we compute the equally-weighted average of the three Blau's indices for gender, ethnicity, and nationality.

Validation of deep-level and surface-level board diversity measures. To ensure that our measures for deep-level and surface-level board diversity capture the effects of information and social categorization biases respectively, we conduct additional validation tests. First, if deep-level board diversity enhances information diversity whereas surface-level board diversity enhances social categorization processes, then we are more likely to observe that surface-level board diversity leads to disharmony or discord among board members as opposed to deep-level board diversity. Assuming that discord or disharmony among board members is likely to lead to (1) board resignations and (2) poor attendance of directors in board meetings, we run analyses regressing the number of board resignations and number of meetings where there was less than 75% attendance from board members on both deep-level and surface-level board diversity measures. Consistent with our expectation, we find that surface-level board diversity is positively associated with director resignations, and that deep-level board diversity is negative and significantly associated with poor board attendance. These analyses suggest that deep-level and surface-level board diversity capture the different aspects relating to information access and social categorization processes (refer to Appendix Table A1).

Second, to ensure that our deep-level diversity and surface-level diversity measures are robust to our choice of components, we explore alternative diversity measures that consider all possible combinations of the five sub-components. In essence, if our operationalization of deep-level diversity (i.e., industry experience, tenure) and surface-level diversity (i.e., gender, ethnicity, and nationality) correctly categorizes one type of diversity from the other, then the choice of diversity components from one or both of these buckets would produce a corresponding composite measure that reveals a pattern that is consistent

with our expectation of the relation between board diversity and innovation. We explore 26 possible combinations given our five different diversity measures (i.e., C(5,2)+C(5,3)+C(5,4)+C(5,5)=26). We find that, when a composite measure includes diversity components relating more to deep-level diversity than to surface-level diversity, the composite measure is, on average, more positively associated with innovation output (refer to details in Appendix Table A2-1, Table A2-2, and Figure A2). These results suggest that the underlying diversity components correspond closely to deep-level and surface-level aspects of board diversity.

Board-CEO committee co-involvement. To measure the degree to which board members are involved in different sub-committees with a CEO, we first examine each CEO-director dyad on the focal board and code '1' if they are joint members in sub-committees within a given focal board and '0' otherwise. Next, we aggregate this measure at the board level by taking the sum of dyads for which a CEO and director were co-involved in the same committee, divided by the total number of all possible CEO-director dyads. Thus, *Board-CEO committee co-involvement* captures the extent to which a board and its CEO have formal committee interactions with each other.

Board-CEO external social ties. To capture whether a board and its CEO have interactions beyond the focal board, we examine for each CEO-director dyad and code '1' if both a CEO and director share common memberships or are affiliated with one or more external organizations, and '0' otherwise. Next, we take the count of dyads for which the CEO and director have external social ties and divide it by the total number of CEO-director dyads. Hence, *Board-CEO external social ties* captures the extent to which a board and its CEO have outside social interactions with each other. While we construct this measure to capture the degree of informality between board members and a CEO, this measure may not be perfect. For instance, CEOs and board members may share common ties or memberships

in privately held organizations that we are not able to observe fully in our current measure. Some of these omitted or underreported informal social relations could be crucial in moderating the effects of board diversity on innovation, thus undermining the statistical significance of our findings. Thus, if there is any bias in this measure, the bias is a conservative one.

Control variables. We control for CEO and firm characteristics that may correlate with a firm's future innovations, and measure all control variables for firm *i* in fiscal year *t*. At the CEO level, we control for *CEO age*, measured by a CEO's age in years. We include the variable *CEO board tenure,* which is measured by the number of years since a CEO is first appointed to his/her position to the board. We also measure *CEO gender,* and code this measure '1' if the CEO is female, and '0' otherwise.

At the firm level, *firm size* is measured as the natural logarithm of a firm's total market capitalization. We also control for a firm's financial condition by including *book leverage*, measured by total debt-to-total assets. To control for a firm's *R&D* funding that could affect innovation activities, we include *R&D expenditures*, measured as R&D expenditures scaled by total assets. Similarly, a focal firm's capital expenditures may also reflect spending to support innovation-related activities; hence, we also control for *Capex*, measured as capital expenditures scaled by total assets. To control for prior operating performance, we include the measure of *ROA*, which is a firm's return-on-assets ratio. Because external investors may affect the type of innovation activities that a focal firm pursues (David et al., 2001), we include the variable *institutional ownership,* which captures the fraction of shares held by institutional investors. We winsorize these firm-level control variables at the 99th percentile to eliminate the influence of extreme outlier values.

At the board level, we control for *board size* by calculating the number of directors on a board in a particular year. We also control for *board independence* by computing the

fraction of independent directors on a board. Finally, we include the variable *board expertise*, measured as the fraction of board members with prior experience in technology- or R&D-related positions.

Estimation

Our main econometric model focuses on the relation between patent-based measures of future innovation-related outcomes ($Innovation_{i,t+3}$) for firm *i* at *t*+3, and measures of deep-level board diversity ($DEEP\_DIVERSITY_{i,t}$), surface-level board diversity ($SURFACE\_DIVERSITY_{i,t}$), board-CEO committee co-involvement ($COMMITTEES_{i,t}$), and board-CEO external ties ($EXT\_TIES_{i,t}$). Specifically, we estimate the following OLS regression:

$$Innovation_{i,t+3} = \propto + \beta_1 DEEP\_DIVERSITY_{i,t} + \beta_2 DEEP\_DIVERSITY_{i,t} \times COMMITTEES_{i,t} + \beta_3 DEEP\_DIVERSITY_{i,t} \times EXT\_TIES_{i,t} + \beta_4 SURFACE\_DIVERSITY_{it} + \beta_5 SURFACE\_DIVERSITY_{i,t} \times COMMITTEES_{i,t} + \beta_6 SURFACE\_DIVERSITY_{i,t} \times EXT\_TIES_{i,t} + \beta' CONTROLS_{i,t} + YEAR_t + FIRM_i + \varepsilon_{it},$$

in which *i* and *t* index firm and time, respectively. $CONTROLS_{it}$ denotes a group of control variables including CEO, director, and firm characteristics that may correlate with a firm's innovations. For all specifications, we also control for year and firm fixed effects, addressing unobserved time-specific effects and time-invariant firm effects. We cluster standard errors by firm to deal with possible auto-correlation in innovation output over time, which could potentially inflate the statistical significance of our estimated coefficients (Cameron and Miller, 2015; Rogers, 1993).

RESULTS

Main results

Table 1 reports descriptive statistics and correlations for the variables we estimate in our analyses.

——INSERT TABLE 1 ABOUT HERE——

We examine our results for each dependent variable in turn. Table 2 displays the results of our OLS regression analyses that predict firm innovation by using the logged patent count measure (*patents*). Model 1 presents the results for the analyses that include only our control variables. In Models 2 through 4, we include our key independent and moderating variables. Model 5 is the fully specified model.

Hypothesis 1a suggests that there is a positive association between deep-level board diversity and innovation. In Model 2, the coefficient estimate for *deep-level board diversity* is positive and statistically significant (β=0.394, $p<0.01$). The coefficient estimate for *deep-level board diversity* is also positive and significant in various specifications in Models 2 through 5. Thus, we find support for Hypothesis 1a. In terms of economic magnitude, the estimate in Model 5 (β=0.235, $p<0.1$) suggests that a one-standard-deviation increase in deep-level board diversity from its average increases a firm's patent output by 3.83% ((exp(0.235×0.16)-1)×100).

Hypothesis 1b posits a negative association between surface-level board diversity and innovation outcomes. In Model 2, we find that the coefficient estimate for *surface-level board diversity* is negative but not statistically significant (β=-0.111, *n.s.*). However, the coefficient for surface-level board diversity is negative and significant (β=-0.334, $p<0.05$) in the fully specified Model 5, which includes additional moderating variables. These findings imply that the presence of the negative effect of surface-level board diversity is contingent on the levels of other moderating variables. Thus, we only find support for Hypothesis 1b in the fully specified model. In terms of economic magnitude, the estimate in Model 5 suggests that a

one-standard-deviation increase in surface-level board diversity from its average decreases a firm's patent output by 4.57% ((exp(-0.334×0.14)-1)×100).

Hypothesis 2a predicts that board-CEO committee co-involvement will strengthen the effect of deep-level board diversity. Model 3 adds the interaction term between *deep-level board diversity* and *board-CEO committee co-involvement*. The coefficient estimate of the interaction term is significant in predicting a firm's patent count (β=1.139, $p<0.01$). The coefficient estimate of the interaction term is also positive and significant in the full Model 5 (β=1.128, $p<0.01$). Thus, we find support for Hypothesis 2a. In terms of economic magnitude, the estimate in Model 5 suggests that a one-standard-deviation increase in board-CEO committee co-involvement further increases the average effect of deep-level board diversity on patent output by 14.6% ((exp(1.128×0.17×0.71)-1)×100).

Hypothesis 2b posits that board-CEO committee co-involvement weakens the negative association between surface-level board diversity and innovation. In Model 3, the coefficient estimate of the interaction between *surface-level board diversity* and *board-CEO committee co-involvement* is positive and significant (β=1.102, $p<0.05$). Similarly, the coefficient estimate is positive and significant in Model 5 (β=1.031, $p<0.05$). We find support for Hypothesis 2b: the greater the board-CEO committee co-involvement, the weaker the negative effect of surface-level board diversity has on a firm's patent output. The estimate of the interaction term in Model 5 suggests that a one-standard-deviation increase in board-CEO committee co-involvement decreases the average negative effect of surface-level board diversity on patent output by 6.9% ((exp(1.031×0.17×0.38)-1)×100).

Hypothesis 3a predicts that board-CEO external social ties will strengthen the effect of deep-level board diversity. In both Model 4 and Model 5, the interaction term between *deep-level board diversity* and *board-CEO external social ties* is positive but not significant

in predicting a firm's patent count (Model 4: β=0.350, *n.s.*, Model 5: β=0.271, *n.s.*). Thus, we do not find support for Hypothesis 3a.

Hypothesis 3b posits that board-CEO external social ties will weaken the negative effect of surface-level board diversity on innovation. In both Model 4 and Model 5, the interaction term between *surface-level board diversity* and *board-CEO external social ties* is positive and significant in predicting a firm's patent count (Model 4: β=2.355, $p<0.01$; Model 5: β=2.266, $p<0.01$). Thus, unlike Hypothesis 3a, Hypothesis 3b is supported by our analyses in Table 2. The estimate of the interaction term in Model 5 suggests that a one-standard-deviation increase in board-CEO external social ties decreases the average negative effect of surface-level board diversity patent output by 10.9% ((exp(2.266×0.12×0.38)-1)×100).

——INSERT TABLE 2 ABOUT HERE——

Next, we turn to the results of our analysis in which we predict firm innovation by using the citation count measure (*citations*), as captured in Table 3. As before, Model 1 presents the results for the analyses that include only our control variables. In Models 2 through 4, we include our key independent and moderating variables, while Model 5 is the fully specified model.

We find support for Hypothesis 1a when we use citations as the alternative measure of innovation. In Model 2, the coefficient estimate for *deep-level board diversity* is positive and statistically significant (β=0.412, $p<0.01$). The coefficient estimate for *deep-level board diversity* is also positive and significant in various specifications in Models 2 through 5. In terms of economic magnitude, the coefficient estimate in Model 5 (β=0.241, $p<0.1$) suggests that a one-standard-deviation increase in deep-level board diversity from its average increases the citations of a firm's patents by 3.93% ((exp(0.241×0.16)-1)×100).

As in Table 2, we find partial support for Hypothesis 1b, which predicts a negative association between surface-level board diversity and the citation count measure. The

coefficient estimates of surface-level board diversity are negative and significant in the fully specified Model 5 (β=-0.355, p<0.05), suggesting the contingency effect of surface-level board diversity. In terms of economic magnitude, the estimate in Model 5 suggests that a one-standard-deviation increase in surface-level board diversity from its average decreases a firm's citation count by 4.85% ((exp(-0.355×0.14)-1)×100).

We also find support for Hypothesis 2a, which predicts the strengthening effect of board-CEO committee co-involvement on the relationship between deep-level board diversity and citation count. In Model 3, the coefficient estimate of the interaction term is significant in predicting a firm's patent count (β=1.241, p<0.01). The coefficient estimate of the interaction term is also positive and significant in the full Model 5 (β=1.231, p<0.01). In terms of economic magnitude, the estimate in Model 5 suggests that a one-standard-deviation increase in board-CEO committee co-involvement further increases the average effect of deep-level board diversity citation count output by approximately 16% ((exp(1.231×0.17×0.71)-1)×100).

We also find support for Hypothesis 2b, which suggests board-CEO committee co-involvement will weaken the negative relationship between surface-level board diversity and citation count. In both Models 3 and 5, the coefficient estimate of the interaction term is positive and significant in predicting a firm's patent count (Model 3: β=1.135, p<0.05; Model 5: β=1.062, p<0.05). The estimate in Model 5 suggests that a one-standard-deviation increase in board-CEO committee co-involvement decreases the average negative effect of surface-level board diversity on citation count by about 7.1% ((exp(1.062×0.17×0.38)-1)×100).

Just as Hypothesis 3a was not supported when we used patent output as our dependent variable, we do not find support when we use citation count as the alternative innovation measure. In both Model 4 and Model 5, the interaction terms between *deep-level board diversity* and *board-CEO external social ties* are positive but not significant in predicting a

firm's citation count (Model 4: β=0.328, *n.s.*; Model 5: β=0.243, *n.s*). However, we find support for Hypothesis 3b in that board-CEO external social ties weaken the negative impact of surface-level board diversity. In both Model 4 and Model 5, the interaction term between *surface-level board diversity* and *board-CEO external social ties* is positive and significant in predicting the firm's citation count (Model 4: β=2.408, $p<0.01$; Model 5: β=2.316, $p<0.01$). The estimate of the interaction term in Model 5 suggests that a one-standard-deviation increase in board-CEO external social ties decreases the average negative effect of surface-level board diversity on citation count by around 11.1% ((exp(2.316×0.12×0.38)-1)×100).

Overall, the results of Table 3 suggest a very similar pattern of results, even when we predict citation count as an alternative measure of innovation output. We find strong support for Hypotheses 1a, 2a, 2b, and 3b when we use either measure of firm innovation. Finally, we find partial support for Hypothesis 1b, while Hypothesis 3a was not supported.

Addressing endogeneity

As we are interested in studying how board diversity and its interactions with formal and informal board structures affects a firm's innovation, we must rule out other potential sources of endogeneity. For instance, there may be omitted variables driving both board diversity and innovation performance. There could also be a potential issue of reverse causality, such that more innovative firms are likely to appoint diverse directors. To alleviate concerns about these sources of endogeneity, we conduct a supplementary analysis that uses a two-stage residual inclusion (2SRI) technique (Terza et al., 2008). Like 2SLS, the first step of 2SRI involves regressing the potentially endogenous variable to all the right-hand side exogenous variables and instruments. However, unlike 2SLS, the second-stage regression of 2SRI includes the residuals rather than predicted values from the first-stage regression, along with the endogenous variable. For the first-stage equation, we instrument *deep-level board diversity* with plausibly exogenous death events of board directors, in which changes in board

diversity are likely to be exogenously determined after these death events. Similarly, we also instrument *surface-level board diversity* by using the death events of board directors. From our first-stage regressions for both *deep-level board diversity* and *surface-level board diversity*, we retain the residuals and use them in the second-stage equations that predict innovation. We find that the pattern of results of our analyses when we use these instrumented board diversity measures remains similar to that of our main results (see Appendix Table A3).

DISCUSSION

Despite the burgeoning interest among management scholars and practitioners on how board diversity influences a firm's innovation, recent empirical research findings about the impact of board diversity on innovation have remained mixed. We contend that these inconsistent findings can be explained by at least two reasons. First, the mechanisms through which board diversity affects innovation have remained under-investigated (c.f., Boivie et al., 2016; Post et al., 2021). Only recently have management scholars used multiple case studies, for example, to understand how board members collaborate with CEOs and management to shape firm-level innovation (e.g., Klarner et al., 2020). Second, existing studies tend to focus on different dimensions of diversity without considering the explicit nature of diversity itself. Although advances in diversity have highlighted that diversity can be surface-level or deep-level, such considerations about the nature of diversity have not been incorporated into research on boards. Indeed, Boivie et al (2016) noted that in the board literature "diversity is typically separated into two areas within extant board literature: demographic and functional, although there are others such as cognitive diversity (Miller et al., 1998) that have been used in the broader literature on groups and teams, but have not been used in board research" (Boivie et al., 2016, p. 338).

We complement and contribute to this stream of research by developing a theory of how board diversity affects firm innovation. Specifically, we conceptualize board diversity into its deep-level and surface-level aspects (Harrison et al., 2002; Phillips and Loyd, 2006), and analyze how these two aspects of board diversity affect a board's monitoring and advising roles, which are both crucial in promoting firm innovation. We suggest that deep-level board diversity has a positive effect on a firm's innovation because it increases board and managerial access to different types of knowledge and informational perspectives, while surface-level board diversity has an opposing negative effect because it can trigger social categorization processes that undermine collaborative efforts. Moreover, we theorize how formal and informal social structures could amplify the positive effect of deep-level board diversity and attenuate the negative effect of surface-level board diversity. Specifically, we hypothesize that board-CEO committee co-involvement (as a form of formal social structure) enhances the effect of deep-level diversity because it increases opportunities for CEOs and board members to engage in more meaningful discussions, while it weakens the negative effect of surface-level diversity because it promotes interactions between board members and CEOs that otherwise would not have occurred because of social categorization processes. We also suggest how board-CEO external social ties could serve as informational conduits to enhance access to deep-level information, while also helping to downplay and blur the social categories that are perceived among demographically different board members.

Although not all our hypotheses received empirical support in our analyses, the collective findings of our study provide insights into why and when board diversity has a positive or negative influence on a firm's innovation. First, we find strong support that deep-level board diversity has a positive main effect on innovation, whereas the negative main effect of surface-level board diversity is not always significant. This pattern of results is consistent with prior studies that found a strong positive effect of board diversity (as an

aggregate index measure) on innovation and suggests that these prior results are more likely driven by deep-level aspects of board diversity rather than surface-level diversity. Moreover, our findings suggest that the negative effect of surface-level diversity is likely contingent on the presence of formal or informal social structures. Specifically, the negative effect of surface-level board diversity becomes significant when either board-CEO committee co-involvement is low, or when board-CEO external social ties are few. Collectively, our findings contribute to the board literature by suggesting important contingencies under which board diversity may have a negative influence on firm innovation. Rather than postulating that the negative effect arises non-linearly when there is "too much" diversity, our findings provide a more nuanced view: that the negative impact of board diversity emerges when auxiliary support social structures—be they formal or informal—are absent. Thus, our study indicates that social structures might be an important board design element that can substantially amplify or undermine the benefits of board diversity. Future research could examine this line of inquiry further by considering whether other elements of board design could similarly moderate the effect of surface-level board diversity on innovation.

Second, we did not find support for the prediction that board-CEO external social ties will strengthen the effect of deep-level board diversity. We speculate that deep-level knowledge and perspectives that are pertinent to a focal firm are also more likely to be firm-specific and thus more likely to be accessed via local interactions within a given focal board (we note that this is consistent with our other finding that board-CEO committee co-involvement strengthens the effect of deep-level board diversity). Rather, board-CEO external social ties only served to weaken the negative effects of surface-level board diversity. These collective findings prove interesting, as management scholars have long speculated how social ties serve as important information conduits for information access among diverse board members and CEOs (Belliveau et al., 1996; Tasheva and Hillman,

2019). These conduits, especially across diverse set of specialized individuals, can foster common understanding and collaboration necessary for innovation (Ter Wal et al., 2016, 2020). However, our empirical findings suggest that the benefits of social ties among board members serve not so much as information conduits, but rather as important social cues about board members' multiple social categories that could help attenuate social categorization biases. Our study thus contributes to research on board diversity by highlighting the need to consider alternative mechanisms through which social structures can enhance the impact of board diversity on innovation-related decision-making (Post et al., 2021).

Relatedly, our study also contributes to corporate governance and board research by highlighting the need to consider a more nuanced view of how CEOs depend on boards for resources. The resource dependency view often highlights how the appointment of diverse board members is important, often assuming that the mere presence of these board members can directly provide CEOs with access to resources (Hillman and Dalziel, 2003). However, this literature has not considered whether access to diverse board resources depends on interactions themselves between boards and CEOs. Our theory and findings complement this stream of research by confirming that CEOs' resource dependency is also dependent upon formal and informal social structures (He and Huang, 2011; Krackhardt, 1994) already in place among board members and CEOs. However, as we were not able to observe board processes directly for this study, we were neither able to code for what type of resources are shared and accessed among diverse board members, nor code for the extent to which board members engage in social categorization. Future research might wish to expand on this contingency perspective of resource dependency by examining or investigating decision processes among diverse board members more directly. Alternatively, scholars who may have access to information about board discussions, such as board meetings collected over time

(e.g., Tuggle et al., 2010), could use large-scale text analysis techniques to measure such social processes indirectly.

Our study also complements the corporate governance literature on board-CEO relations. Scholars have long recognized that social interactions between boards and CEOs have implications for firm governance, and they have examined these interactions from various theoretical perspectives (Boyd et al., 2011). In a review of the literature on board-CEO relations, Boyd et al. (2011) revealed how board-CEO relations have been examined from at least six different theoretical perspectives: agency, resource dependency, upper echelons, stewardship, social network, and institutional. Other than the institutional perspective, most of these theoretical perspectives focus on the instrumentality of board-CEO relations in governing a firm (i.e., the extent to which board-CEO relations play a role in resource and/or power acquisition to enhance the interest of firms and/or managers). In contrast, our findings highlight a non-instrumental, psychological aspect of board-CEO relations that indirectly affects firm-related outcomes. Specifically, we identify how board-CEO relations can help mitigate social categorization processes that diminish the value that diverse boards can otherwise bring to a given firm. In doing so, our study complements existing research by articulating the less-examined cognitive aspect of board-CEO social ties and analyzing how it can shape a board's decision-making processes and, in turn, impact an organization's performance-related outcomes (e.g., Boyd, 1995; Boyd et al., 2011; Westphal, 1999).

Our study has several practical implications. Our findings suggest that while appointing external directors may provide unique expertise and resources that enhance a firm's innovation, such action may benefit firms further if these directors are involved to a greater extent via their inclusion in board committees (i.e., the use of formal arrangements or existing informal structures to design boards) (Clement and Puranam, 2017; He and Huang,

2011), which could improve firms' innovation. For example, when firms are considering appointing board members with diverse deep-level expertise, boards can consider convening committees that include both board members and CEO more frequently. In contrast, if potential board members are demographically diverse, then boards can additionally consider whether these directors have external social connections that could help mitigate the negative impact of surface-level diversity.

Our results also echo recent legislation with respect to gender diversity in Europe (Norway in 2003, Spain in 2007, Belgium, France, Italy, and Netherlands in 2011, and Germany in 2016 (Comi et al., 2017)) and a rise in shareholder proposals pushing for board diversity in the U.S. For example, Washington is the first state to require public companies to have a "gender-diverse board" as of January 1, 2022. We highlight the potential benefits from board diversity in terms of firm-level innovation performance, as innovation activities rely on open mindsets and diversified opinions (Chua et al., 2019; Gao and Zhang, 2017). Moreover, our study suggests that increasing board diversity should not be the sole consideration, but must be considered together with formal and informal social structures that bind CEOs and board members.

Our study has limitations that also suggest future research opportunities. Specifically, although our study focuses on how deep-level and surface-level board diversity influence innovation, we did not examine other firm-level related outcomes linked to deep-level and surface-level board diversity. Thus, future research should further examine how these different aspects of board diversity may influence other strategic decisions, such as acquisitions and diversification. For instance, our theory suggests that boards with greater deep-level diversity and/or lesser surface-level diversity will be better positioned to evaluate potential merger deals. In addition, we speculate that formal and informal social structures of directors could further strengthen the positive effects of deep-level board diversity, as well as

weaken the negative effects of surface-level board diversity on a board's ability to make prudent acquisition-related decisions (e.g., limiting acquisition premiums) (Chen et al., 2016). Moreover, future research could further investigate whether deep-level and surface-level board diversity influences how CEOs and top management team members make executive decisions at the firm level. Because the strategic choices of top executives reflect their values and cognitive biases (Hambrick, 2007; Hambrick and Mason, 1984), top executives who frequently collaborate with boards with high deep-level or surface-level diversity may make systematically different choices, as compared to top executives who work with boards with less deep-level or surface-level diversity.

Although our results based on measures of deep-level and surface-level board diversity are consistent with our hypotheses, our measures are archival data-based measures and thus only noisy approximations of the true underlying diversity constructs. Moreover, our measures of innovation outcomes have high variability (due to the uncertain nature of the patenting and citation process), and only a small portion of the variance is explained by our board diversity measures. Although we have sought to control as many related factors as possible to obtain our estimations, we are unable to completely exclude all possible inferences. Nevertheless, our estimations provide a conservative test of our theory and hypotheses. Future research may consider assessing these various dimensions of board diversity more directly and investigate our theorized mechanisms by using a different research design, such as through surveys (e.g., Bednar and Westphal, 2006) or interviews (e.g., Klarner et al., 2020).

Overall, our study highlights the importance of viewing boards not simply as overseers of management, but rather as important participants in the innovation process. We have shown that structuring boards in a way that accounts for multiple dimensions of director diversity leads to different innovation-related outcomes. Future research may examine this

link in greater detail or investigate other pathways through which boardroom decisions could affect a firm's innovation performance. Indeed, although board members are usually not directly involved in the creation of innovations themselves, they strongly influence the innovation process by setting the broader strategic direction and technology trajectory of their respective organizations (Klarner et al., 2020; Useem et al., 2014). Board composition can thus be regarded as an important component of a firm's human capital and a critical determinant of its intellectual property that, in turn, impacts a firm's long-term value.

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Figure 1. Summary of theorized mechanisms linking board diversity to firm innovation

Type of board diversity	Effect on innovation outcome	Formal/informal social structure between Board-CEO	Hypothesized mechanisms underlying how social structures moderate the effects of board diversity
Deep-level board diversity	**Positive**: Enhance CEO's access to knowledge and information variety of board members (H1a)	Board-CEO committee co-involvement	**Strengthen**: Formal working arrangements on specific board tasks increases frequency of board and CEO interactions (H2a)
		Board-CEO external social ties	**Strengthen**: Social ties beyond focal board serve as additional conduits of information access between board and CEO (H3a)
Surface-level board diversity	**Negative**: Social categorization leads to subgroup formation that hinders board collaboration with CEO (H1b)	Board-CEO committee co-involvement	**Weaken**: Imposes collaborative interactions between board and CEO, which would have otherwise unlikely occurred because of social categorization processes (H2b)
		Board-CEO external social ties	**Weaken**: Reduces social categorization processes between CEO and board by increasing perceptions of common memberships between subgroups (H3b)

Table 1. Descriptive statistics and correlations

	Variables	Mean	S.D.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1)	Patent count (log)	0.36	0.97																	
(2)	Citation count (log)	0.34	1.02	0.942																
(3)	Deep-level board diversity	0.71	0.16	0.211	0.188															
(4)	Surface-level board diversity	0.38	0.14	-0.143	-0.139	-0.094														
(5)	CEO age	67.42	9.03	0.107	0.102	0.088	-0.235													
(6)	CEO board tenure	9.17	8.93	-0.038	-0.037	0.151	-0.111	0.442												
(7)	CEO gender	0.03	0.17	-0.014	-0.013	0.008	0.104	-0.056	-0.050											
(8)	Firm size	6.36	2.03	0.252	0.231	0.335	-0.136	-0.007	-0.041	0.001										
(9)	Book leverage	0.22	0.22	-0.068	-0.064	0.048	-0.039	-0.026	-0.060	-0.012	0.147									
(10)	Capex	0.04	0.05	0.006	0.010	0.044	-0.054	0.013	0.001	0.000	0.091	0.091								
(11)	ROA	0.04	0.22	0.054	0.047	0.195	-0.134	0.110	0.119	-0.015	0.373	0.083	0.149							
(12)	Board independence	0.76	0.17	0.035	0.025	0.143	0.090	-0.106	-0.087	0.024	0.105	-0.055	-0.046	-0.006						
(13)	Board size	8.33	2.59	0.082	0.072	0.253	-0.057	0.060	-0.034	0.003	0.485	0.083	-0.070	0.162	0.030					
(14)	Institutional ownership	0.28	0.36	0.187	0.170	0.158	-0.174	0.098	-0.001	-0.017	0.235	0.017	0.028	0.182	0.072	0.075				
(15)	Board expertise	0.07	0.26	0.130	0.118	0.076	-0.015	-0.001	0.006	-0.021	0.090	-0.033	-0.006	-0.004	-0.012	0.051	-0.105			
(16)	R&D expenditure	0.12	0.27	0.153	0.139	-0.012	0.100	-0.112	-0.085	0.019	-0.177	-0.150	-0.092	-0.633	0.054	-0.182	-0.038	-0.008		
(17)	Board-CEO external social ties	0.05	0.12	-0.083	-0.075	-0.273	-0.001	0.000	-0.024	-0.015	-0.007	0.053	-0.031	-0.029	-0.153	0.037	-0.061	-0.030	-0.078	
(18)	Board-CEO committee co-involvement	0.10	0.17	0.037	0.034	0.057	-0.131	0.146	0.087	0.004	0.115	0.038	-0.014	0.077	-0.063	0.153	0.060	0.030	-0.079	0.028

N=42,432. All correlations greater than 0.008 are significant at the p=0.05 level.

Table 2. Regression analyses predicting patent output

VARIABLES	(1)	(2)	(3)	(4)	(5)
Firm size	0.008	0.007	0.008	0.007	0.008
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Leverage-to-book ratio	-0.153**	-0.159**	-0.153**	-0.156**	-0.150**
	(0.067)	(0.067)	(0.066)	(0.066)	(0.066)
Capex	0.108	0.096	0.082	0.090	0.077
	(0.147)	(0.147)	(0.147)	(0.147)	(0.147)
ROA	-0.273***	-0.276***	-0.275***	-0.274***	-0.274***
	(0.051)	(0.051)	(0.051)	(0.051)	(0.051)
Board independence	0.013	-0.016	-0.020	-0.014	-0.017
	(0.059)	(0.060)	(0.060)	(0.060)	(0.060)
Board size	-0.008	-0.012**	-0.011*	-0.012*	-0.011*
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Institutional ownership	0.163***	0.164***	0.162***	0.161***	0.159***
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)
Board expertise	-0.071	-0.076	-0.075	-0.077	-0.076
	(0.124)	(0.124)	(0.123)	(0.124)	(0.123)
R&D expenditures	-0.327***	-0.345***	-0.335***	-0.336***	-0.327***
	(0.071)	(0.071)	(0.071)	(0.071)	(0.071)
CEO age	0.002	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
CEO board tenure	0.001	0.000	0.000	0.000	0.000
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
CEO gender	-0.021	-0.026	-0.027	-0.024	-0.026
	(0.086)	(0.087)	(0.087)	(0.086)	(0.087)
Deep-level board diversity (H1a: +)		0.394***	0.250**	0.373***	0.235*
		(0.115)	(0.121)	(0.119)	(0.125)
Surface-level board diversity (H1b: –)		-0.110	-0.255*	-0.202	-0.334**
		(0.122)	(0.141)	(0.126)	(0.144)
Board-CEO committee co-involvement		0.068	-1.154***	0.067	-1.122***
		(0.081)	(0.312)	(0.081)	(0.310)
Board-CEO external social ties		-0.162**	-0.159**	-1.206***	-1.125***
		(0.073)	(0.072)	(0.218)	(0.213)
Deep-level board diversity			1.139***		1.128***
x Board-CEO committee co-involvement (H2a: +)			(0.417)		(0.415)
Surface-level board diversity			1.102**		1.031**
x Board-CEO committee co-involvement (H2b: +)			(0.444)		(0.441)
Deep-level board diversity				0.350	0.271
x Board-CEO external social ties (H3a: +)				(0.336)	(0.334)
Surface-level board diversity				2.355***	2.266***
x Board-CEO external social ties (H3b: +)				(0.392)	(0.383)
Constant	0.749***	0.567***	0.725***	0.607***	0.757***
	(0.158)	(0.168)	(0.168)	(0.169)	(0.170)
Observations	42,432	42,432	42,432	42,432	42,432
R-squared	0.712	0.712	0.713	0.713	0.713
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

Robust standard errors clustered by firm are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Regression analyses predicting citation output

VARIABLES	(1)	(2)	(3)	(4)	(5)
Firm size	-0.002	-0.004	-0.003	-0.003	-0.002
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Leverage-to-book ratio	-0.174**	-0.180**	-0.174**	-0.177**	-0.171**
	(0.077)	(0.077)	(0.077)	(0.077)	(0.077)
Capex	0.137	0.126	0.112	0.121	0.107
	(0.170)	(0.170)	(0.170)	(0.169)	(0.169)
ROA	-0.320***	-0.323***	-0.322***	-0.321***	-0.321***
	(0.065)	(0.065)	(0.065)	(0.065)	(0.065)
Board independence	0.070	0.038	0.034	0.041	0.037
	(0.067)	(0.068)	(0.068)	(0.068)	(0.068)
Board size	-0.010	-0.014**	-0.013*	-0.013**	-0.013*
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Institutional ownership	0.155***	0.156***	0.154***	0.153***	0.151***
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Board expertise	-0.058	-0.064	-0.063	-0.064	-0.063
	(0.133)	(0.132)	(0.132)	(0.132)	(0.132)
R&D expenditures	-0.413***	-0.431***	-0.420***	-0.422***	-0.412***
	(0.090)	(0.089)	(0.089)	(0.089)	(0.090)
CEO age	0.001	0.002	0.001	0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
CEO board tenure	0.002	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
CEO gender	-0.033	-0.036	-0.038	-0.035	-0.037
	(0.090)	(0.090)	(0.090)	(0.090)	(0.090)
Deep-level board diversity (H1a: +)		0.412***	0.254**	0.392***	0.241*
		(0.124)	(0.129)	(0.130)	(0.134)
Surface-level board diversity (H1b: –)		-0.125	-0.274*	-0.219	-0.355**
		(0.132)	(0.151)	(0.137)	(0.155)
Board-CEO committee co-involvement		0.029	-1.279***	0.028	-1.248***
		(0.086)	(0.331)	(0.086)	(0.328)
Board-CEO external social ties		-0.160**	-0.157**	-1.211***	-1.125***
		(0.079)	(0.079)	(0.231)	(0.227)
Deep-level board diversity			1.241***		1.231***
x Board-CEO committee co-involvement (H2a: +)			(0.445)		(0.443)
Surface-level board diversity			1.135**		1.062**
x Board-CEO committee co-involvement (H2b: +)			(0.473)		(0.470)
Deep-level board diversity				0.328	0.243
x Board-CEO external social ties (H3a: +)				(0.374)	(0.373)
Surface-level board diversity				2.408***	2.316***
x Board-CEO external social ties (H3b: +)				(0.420)	(0.412)
Constant	0.893***	0.708***	0.877***	0.748***	0.909***
	(0.173)	(0.182)	(0.183)	(0.183)	(0.184)
Observations	42,432	42,432	42,432	42,432	42,432
R-squared	0.646	0.646	0.647	0.647	0.647
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

Robust standard errors clustered by firm are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX

Table A1. Effect of deep-level and surface-level board diversity on board resignations and attendance

VARIABLES	DV: Number of board resignations	DV: Number of meetings with poor board attendance
Deep-level board diversity (1)	-0.011	-0.230***
	(0.075)	(0.032)
Surface-level board diversity (2)	0.214***	-0.036
	(0.056)	(0.032)
F-test of coefficient differences (1)-(2), p-value	0.0237	0.000
Control variables	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	63,148	63,148
R-squared	0.240	0.762

Robust standard errors clustered by firm are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A2-1. All possible 26 combinations of five different diversity measures (nationality, ethnicity, gender, tenure, and industry), and their corresponding diversity deepness score. [For instance, for diversity combination (1), the corresponding deepness score is 0.40; for diversity combination (2), the score is 0.25. Our measures of *deep-level board diversity* and *surface-level board diversity* used in our main analyses correspond to combinations (20) and (7), respectively.]

			Possible Combinations Among Five Diversity Components to form 'Deepness' Index																									
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
Type	Component	Weight for deepness	5 choose 5	5 choose 4					5 choose 3										5 choose 2									
Surface-level	Nationality	0	✓	✓	✓	✓	✓		✓			✓	✓	✓		✓		✓	✓				✓			✓		✓
	Ethnicity	0	✓	✓	✓	✓		✓	✓	✓			✓	✓	✓		✓		✓	✓				✓			✓	
	Gender	0	✓	✓	✓		✓	✓	✓	✓	✓				✓	✓		✓		✓	✓		✓		✓			
Deep-level	Tenure	1	✓	✓		✓	✓	✓		✓	✓	✓		✓		✓	✓				✓	✓		✓		✓		
	Industry	1	✓		✓	✓	✓	✓			✓	✓	✓		✓		✓	✓				✓			✓		✓	✓
Diversity deepness score based on diversity combination (1=highest deep-level diversity; 0=highest surface-level diversity)			0.40	0.25	0.25	0.50	0.50	0.50	0.00	0.33	0.67	0.67	0.33	0.33	0.33	0.33	0.67	0.33	0.00	0.00	0.50	1.00	0.00	0.50	0.50	0.50	0.50	0.50

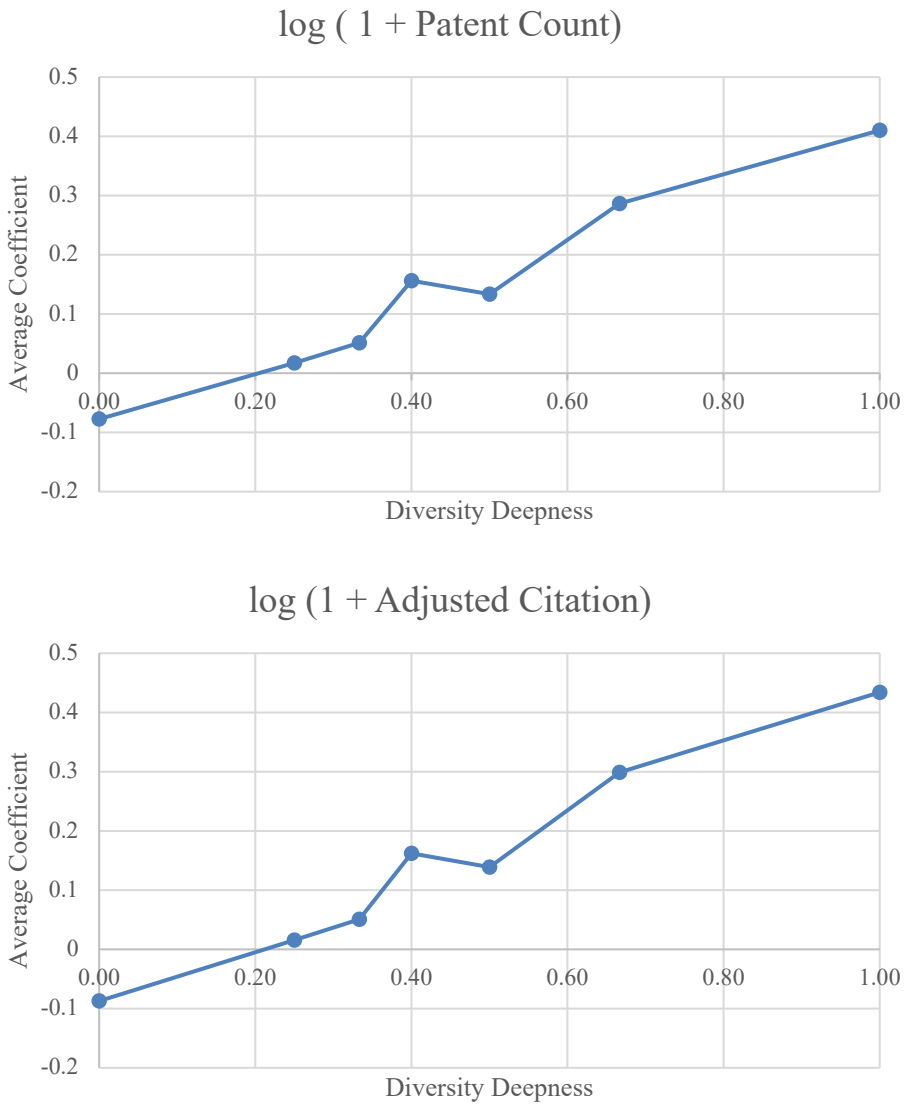
Table A2-2. Regression analyses predicting innovation output using 26 diversity combination indices.

For each of the 26 diversity combination indices (derived in Table A2-1), we estimate the following OLS regression: $Innovation_{i,t+3} = \propto_{i,t} + \beta_1 DIVERSITY_{i,t} + \beta\acute{}\, CONTROLS_{i,t} + YEAR_t + FIRM_i + \varepsilon_{it}$, in which *i* and *t* index firm and time, respectively. $CONTROLS_{it}$ denotes a group of control variables including CEO, director, and firm characteristics that may correlate with a firm's innovations. For all specifications, we also control for year and firm fixed effects, addressing unobserved time-specific effects and time-invariant firm effects. We cluster robust standard errors by firm. We summarize and present the predicted coefficients of each diversity combination for *patent output* and *citation output* from the 52 (26*2) regressions below.

Diversity combination	Diversity deepness score of diversity combination	Coefficient predicting *Patent output*	Coefficient predicting *Citation output*
(7)	0.00	-0.096	-0.106
(17)	0.00	-0.059	-0.049
(18)	0.00	-0.162	-0.196*
(21)	0.00	0.007	0.002
(2)	0.25	0.143	0.115
(3)	0.25	-0.108	-0.084
(8)	0.33	0.131	0.076
(11)	0.33	-0.072	-0.030
(12)	0.33	0.149	0.145
(13)	0.33	-0.190	-0.185
(14)	0.33	0.282**	0.257*
(16)	0.33	0.008	0.042
(1)	0.40	0.156	0.162
(4)	0.50	0.172	0.201
(5)	0.50	0.311**	0.323**
(6)	0.50	0.149	0.131
(19)	0.50	0.320***	0.260**
(22)	0.50	0.139	0.115
(23)	0.50	-0.053	-0.033
(24)	0.50	0.267***	0.268**
(25)	0.50	-0.139	-0.104
(26)	0.50	0.033	0.087
(9)	0.67	0.366**	0.352**
(10)	0.67	0.320**	0.359***
(15)	0.67	0.174	0.186
(20)	1.00	0.410***	0.434***

Robust standard errors clustered by firm are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Figure A2: Visual correlation of diversity deepness score with patent count (top) and citation count (bottom)*



* Note: we computed the average value of the predicted coefficients (taken from Table A2-2) for each corresponding diversity deepness score.

Table A3. Regression models using board diversity measures instrumented by director deaths

VARIABLES	Patent count, t+3	Citation count, t+3
Deep-level board diversity (instrumented) (H1a: +)	0.235*	0.238*
	(0.121)	(0.131)
Surface-level board diversity (instrumented) (H1b: –)	-0.334**	-0.353**
	(0.144)	(0.154)
Board-CEO committee co-involvement	0.073	0.034
	(0.080)	(0.084)
Board-CEO external social ties	-0.078	-0.080
	(0.102)	(0.113)
Deep-level board diversity (instrumented) x Board-CEO committee co-involvement (H2a: +)	1.104***	1.190***
	(0.411)	(0.440)
Surface-level board diversity (instrumented) x Board-CEO committee co-involvement (H2b: +)	1.042**	1.082**
	(0.439)	(0.468)
Deep-level board diversity (instrumented) x Board-CEO external social ties (H3a: +)	0.281	0.247
	(0.335)	(0.373)
Surface-level board diversity (instrumented) x Board-CEO external social ties (H3b: +)	2.265***	2.324***
	(0.382)	(0.410)
Observations	42,432	42,432
R-squared	0.713	0.647
Control variables	YES	YES
Firm FE	YES	YES
Year FE	YES	YES

Robust standard errors clustered by firm are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1